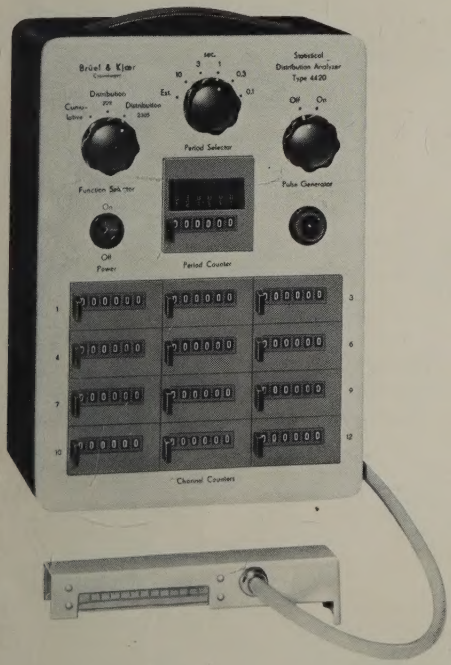
4420

INSTRUCTIONS AND APPLICATIONS

Statistical Distribution Analyser Type 4420



Primarily an accessory for the B & K Level Recorder Type 2305, this instrument resolves measurement data (usually sound levels) into twelve class intervals and presents a numerical display which lends itself to statistical analysis.

- Accelerometers
- Acoustic Standing Wave Apparatus
- Artificial Ears
- Artificial Voices
- Audio Frequency Response Tracers
- Audio Frequency Spectrometers
- Audio Frequency Vacuum-Tube Voltmeters
- Automatic A. F. Response and Spectrum Recorders
- Automatic Vibration-Exciter Control Generators
- Band-Pass Filter Sets
- Beat Frequency Oscillators
- Complex Modulus Apparatus
- Condenser Microphones
- Deviation Bridges
- Distortion Measuring Bridges
- Frequency Analyzers
- Frequency Measuring Bridges
- Hearing Aid Test Apparatus
- Heterodyne Voltmeters
- Level Recorders
- Megohmmeters
- Microphone Accessories
- Microphone Amplifiers
- Microphone Calibration Apparatus
- Mobile Laboratories
- Noise Generators
- Noise Limit Indicators
- Pistonphones
- Polar Diagram Recorders
- Preamplifiers
- Precision Sound Level Meters
- Recording Paper
- Strain Gage Apparatus and Accessories
- Surface Roughness Meters
- Variable Frequency Rejection Filters
- VHF-Converters
- Vibration Pick-ups
- Vibration Pick-up Preamplifiers
- Wide Range Vacuum Tube Voltmeters

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Statistical Distribution Analyser

Type 4420

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1. Statistical Analysis

1.1. Purpose of the 4420.

The Statistical Distribution Analyser Type 4420 is basically an accessory for the Brüel & Kjær Level Recorder, though it can also be attached to other suitable recorders and indicators including the B & K Noise Limit Indicator Type 2211.

Electrical signals representing a great many phenomena, for instance sound, vibration, stress, strain, temperature or pressure, can be plotted graphically on the Level Recorder, and in the controlled conditions of the laboratory some excellent curves (Fig. 1.1) can be obtained. But in everyday life outside

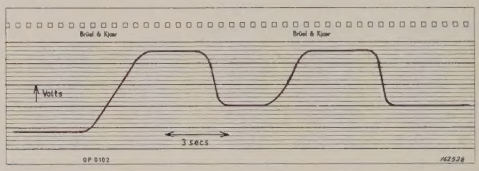


Fig. 1.1. An example of a time-record taken in the laboratory. All the relevant information it contains can be easily read off.

the laboratory, things are not so well ordered and a record of some investigation might look more like Fig. 1.2. What does this graph mean? It tells us firstly that to take one spot measurement at a particular time on, say, traffic noise is almost worthless. Very little can be deduced without resorting to a statistical approach which can express a behaviour otherwise difficult to describe. It is of course possible to carry out this tedious

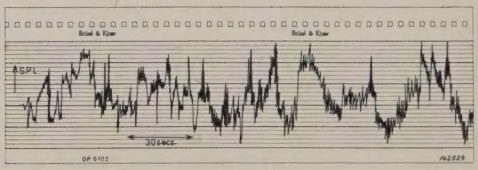


Fig. 1.2. A typical recording of an irregular phenomenon such as traffic noise. No useful data can be extracted without statistical analysis.

statistical analysis graphically at the expense of considerable time and trouble, but a much simpler and more reliable solution is to use a Statistical Distribution Analyser.

The analyser resolves the recorded information into twelve class intervals and presents a numerical display of the data. This is done simultaneously with the writing process and so a paper record need only be taken if required.

1.2. What Sort of Analysis?

The title "Statistical Analysis" is very sweeping, and to consider but one field, that of sound measurements, there are many kinds of statistical analysis which can be applied. The equipment under discussion cannot be used for all of these so it must be made clear at the outset exactly what its capabilities are.

Investigations will normally be confined to the variation of *level* with time, i.e. time is the independent variable.

Note the word *level*. Type 2305 is called a *Level* Recorder because it plots the mean level according to an R.M.S., Average, or Peak law and, except at very low frequencies, it does not record instantaneous values. Even these instantaneous values given by "D.C." recording at low frequencies are "levels", because the instantaneous value of, say, temperature is the same as the level. However, in the case of a quantity such as sound, vibration, or A.C. mains voltage, instantaneous values are certainly not the same as levels.

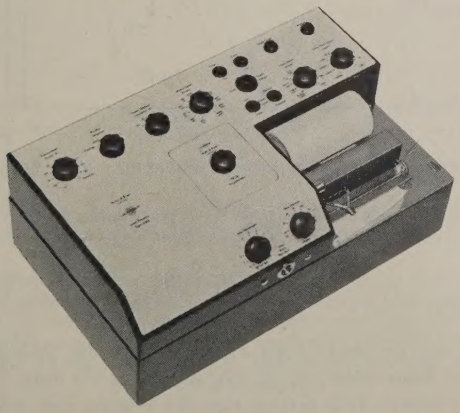


Fig. 1.3. The Level Recorder Type 2305. The Statistical Distribution Analyser Type 4420 includes a set of twelve contacts which are scanned by means of the writing arm of the recorder.

The intrinsic variations in instantaneous values have been the subject of considerably study*) but are not of interest here because the Level Recorder is a rectifying instrument which averages out such variations. The Level Recorder looks at "long term" changes in rectified level**), for instance the rise and fall in sound intensity in a workshop.
The great advantage of statistical analysis is that a reliable estimate of the mean value of a level can be arrived at and also a measure of variability.

1.3. Basic Concepts.
On a record, such as Fig. 1.4 of a varying signal, consider a finite length or time duration T. This signal level x is a function of time (written x(t)), and as seen, the probability of finding x(t) within a given amplitude interval defined by x_1 and $x_1 + \Delta x$ is determined by the proportion of time that the level lies within this interval.

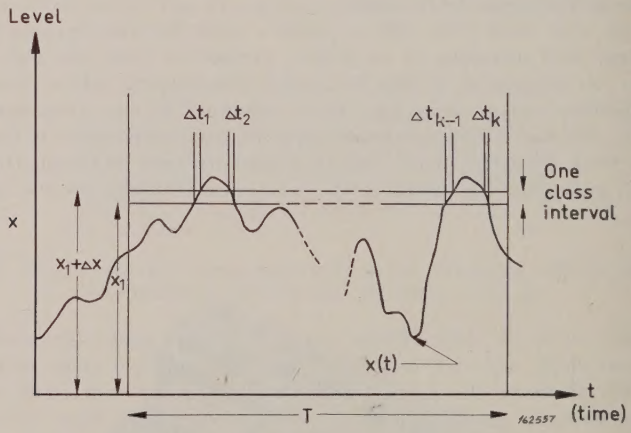


Fig. 1.4. The estimation of magnitude probability of a varying signal level.

Mathematically, the probability that x(t) is greater than x_1 but less than $x_1 + \Delta x$ is

$$P\ (x_1 \leqq x(t) \leqq x_1 + \Delta x) = \frac{\sum_{i=1}^{i=k} \Delta t_1 + \Delta t_2 + \Delta t_3 + \ldots \Delta t_k}{T} \qquad \ldots .1$$

This quantity can be easily read off the Statistical Distribution Analyser for a fixed and finite value of Δx. Δx is 1/12 of the total x range scanned by the Level Recorder. It is certain that the writing arm will lie *somewhere*

*) B & K Technical Reviews No. 4 - 1959 and No. 2 - 1961.
**) Appendix B deals with the recorder characteristics.

within its scanned range, so if the individual probabilities for all 12 class intervals are added together they must come to 1.0, because the probability of a certainty is 1.0.

At some intermediate position X of the writing arm it might be that 60 % of the time the level is less than X, which is the same thing as saying that 40 % of the time it is more than X. The sum of all the probabilities for the class intervals above this X is therefore 0.4, and the probability of the reading being less than X is $1 - 0.4 = 0.6$. A graph showing this idea looks like a descending flight of steps, Fig. 1.5, which if more and more narrower and narrower class intervals were used, would become a smooth curve. In the case of data from the 4420 there are 12 steps, allowing an adequate approximation to the so-called "cumulative probability curve"*). The stepped function is known as the *Cumulative Probability Plot.*

Instead of summing all the probabilities, they can be plotted individually as in Fig. 1.6. The area of this histogram is unity, as also is the area under the smooth curve. The latter would be obtained from a distribution analyser

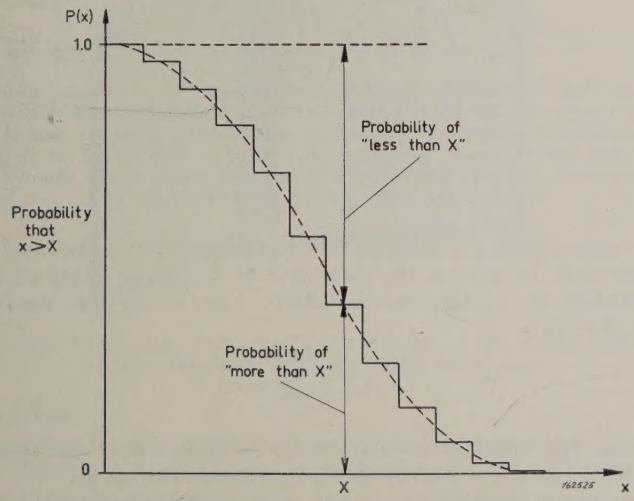


Fig.. 1.5. The Cumulative Probability Plot for a varying signal. This shows the summation of probability for all elements of width Δx above each particular value of x plotted here on the horizontal axis (abscissa). A smooth curve (dotted) would result from using an analyser of infinite resolution. The steps indicate the approximations that are possible using the Statistical Distribution Analyser.

*) In usual statistical parlance, the "Cumulative Frequency Distribution". To prevent confusion, "Frequency" is avoided and "Distribution" is reserved for the probability density function and its approximation.

of infinite resolution, i.e. one splitting the data up into a very large number of small class intervals. In this ideal case the curve of "Probability Density Distribution" would be obtained. The present argument need only concern the approximating histogram which, since it shows the probabilities in each class interval, can simply be called a *Probability Distribution Histogram.*

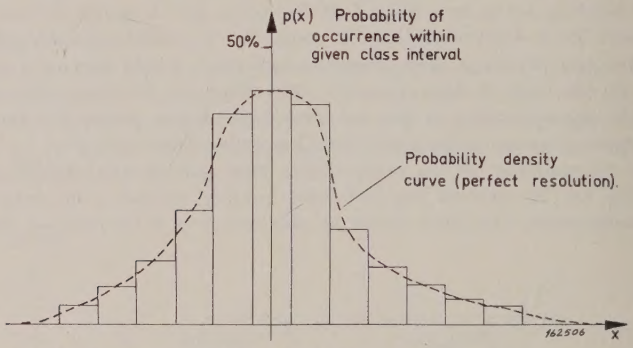


Fig. 1.6. The Probability Distribution Histogram for a varying signal. The full lines (stepped) are derived from Statistical Distribution Analyser readings; with an infinite number of channels a smooth curve (such as that dotted in the figure) would result. Classically this curve is bell-shaped or "Gaussian" but in general this need not be so; not only the nature of the signal but also the recorder characteristics will affect its form.

If the symbol small p is assigned to the probabilities**) within each of the class intervals, i.e. $p(x_1)$ is the probability of occurrence within an interval characterized by x_1, then the probability large $P((x_\alpha)$ that the level is *greater than* x_α is

$$P(x_\alpha) = \sum_{i=\alpha}^{i\,Max} p(x_1) \qquad \ldots .2$$

Note that P(x) and p(x) are respectively the ordinates of the Cumulative Probability Plot and of the Probability Distribution Histogram.
The summation indicated in equation 2 can, with a suitable knob setting, be achieved electronically. This gives the Cumulative Probability Plot similar to Fig. 1.5.
The interprepation of the results is left to the user, but to help him in making estimates of the more important parameters associated with statistical data, some formulae are included in Appendix A.

**) Strictly, small p is reserved for probability density but, since the class intervals are specified, this approach is consistent and has the merit of simplicity.

1.4. Use with Noise Limit Indicator.

The Noise Limit Indicator Type 2211 measures noise or vibration at either one or two points and has 12 frequency-selective output channels, each of which can be monitored by a counter in the Statistical Distribution Analyser. When a noise or vibration exceeds a particular predetermined level in a certain frequency band, one of the counters registers the total time for which the excess occurred. The data obtained can be of great value in long term development tests and type-approval trials on all kinds of machinery.

The basic 2211 is ideally suited to production testing, but when combined with the Statistical Distribution Analyser which is a time-dependent device, no sensible results are possible unless the production process is strictly time-dependent and extraneous signals can be eliminated.

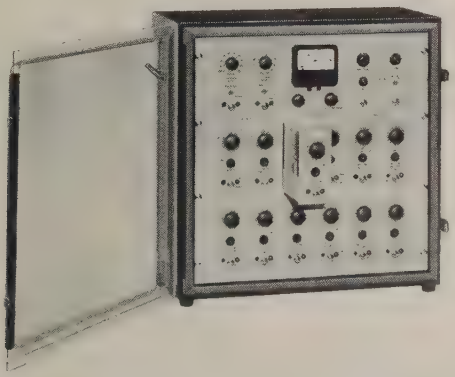


Fig. 1.7. The Noise Limit Indicator Type 2211. One of the twelve frequency-selective amplifiers is shown partly withdrawn.

1.5. Other Uses.

It is possible to make the 4420 record statistical data which is not a function of time. Each case where this has to be done must be treated separately: Chapter 8 contains some suggestions.

2. Brief Description

2.1. Principle.

Fig. 2.1 shows the principle of the Distribution Analyser. A generator produces short pulses, each of which can cause a counter, or counters, to register one more digit. Every pulse is recorded on the Period Counter (total register), and at the same time, if any of the contacts are closed, various of the 12 channel counters will count as well.

The maximum figure on each counter is 999,999.

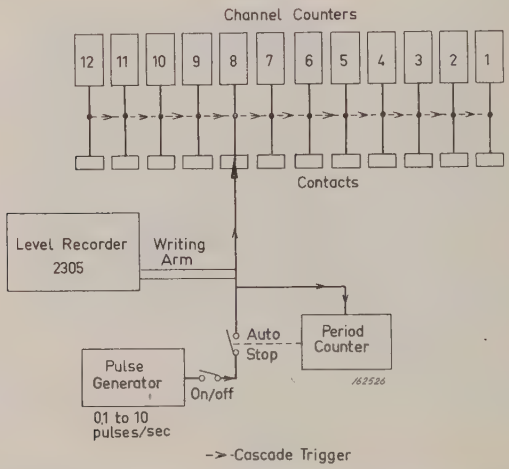


Fig. 2.1. Fundamental principle of the Statistical Distribution Analyser. The cascade trigger is only operative for "cumulative" counting.

2.2. Pulse Generator.

The period between each pulse, i.e. the time between each count, can be selected by means of the PERIOD SELECTOR switch to be

0.1
0.3
1
3
or 10 secs.

Alternatively, the generator is triggered externally to provide one pulse at a time either by a simple make contact or by a negative-going pulse.
The generator can be stopped in three ways:

manually, using the PULSE GENERATOR "On/Off" switch,
automatically as described in the next section,
or remotely by any suitable arrangement of a make contact.

2.3. Automatic Stop.

So that the Analyser operates for only a pre-determined period, a maximum desired total count, or "target" figure, can be set by hand. When the Period Counter reaches this value, counting stops. An added advantage of this facility is that if some power of 10 is set as a target figure it is very easy to read off percentages for the 12 channels.
If the automatic stop is not required, it is prevented from interfering with an experiment by setting the target figure at any high value which will not be reached.

2.4. Contacts.

In normal operation, 12 pairs of make contacts are required in order to cause the various channel counters to register.

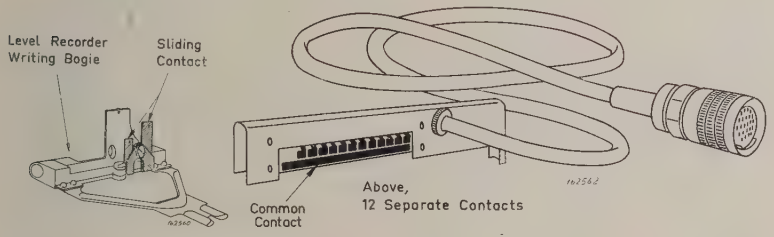


Fig. 2.2. The Contact Device AO 0036 which fixes on top of the writing arm of the Level Recorder, and (left) the Contact Slider OD 0130 which moves with the writing bogie of the recorder.

The contact set supplied with the Statistical Distribution Analyser fits over the writing arm of the Level Recorder Type 2305 so that the chart width is divided into 10 geometrically equal bands. There are two other bands, one just above the chart graduations, and one just below, so that overshoots of the writing arm are also catered for. When the writing stylus is in band 7 (say), contact pair number 7 is made, and so on.
Alternatively, the analyser may be connected to the Noise Limit Indicator Type 2211, in which case the contacts are those on a bank of relays in the 2211.
Special contact sets can be made by the user to suit particular applications: no other sets are marketed by Brüel and Kjær.

2.5. Function Selector.

It is often of interest to draw up a histogram of the kind shown in Fig. 2.3, where the distribution of some quantity is shown up by dividing the range of values into 12 class intervals. The sum of all the channel counter readings must equal the total, or period counter, reading. Unfortunately in intermediate positions of the Level Recorder writing arm, two contacts

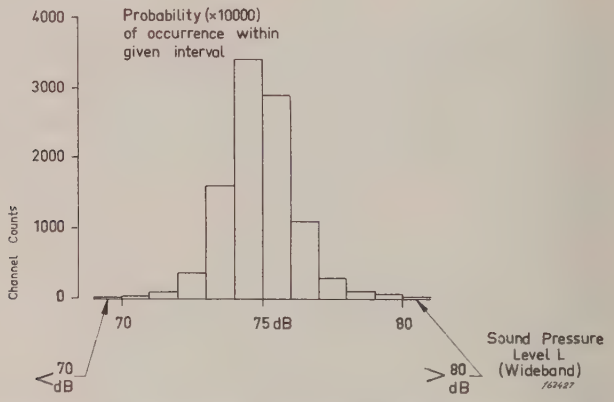


Fig. 2.3. Histogram of probability distribution. Sound pressure levels were recorded for nearly 17 minutes in a machine shop. Note that registering each channel count and dividing by the total figure (for convenience a round number) gives the probabilities that the level lies within the given class intervals, (i.e. shows the fraction of time the level was between certain narrow limits).

Settings: 4420: Distribution — 2305
Total 10,000 digits, period 0.1 sec.
2305: R.M.S.
10 dB range.

will be made at once and a simple system would register too many digits on the channel counters. In the FUNCTION SELECTOR position "Distribution-2305", this is prevented and only one channel can count at a time, thereby ensuring the equality

$$N = n_1 + n_2 + n_3 + \ldots\ldots n_{12},$$

where N = Period Counter (total) reading.

and n_i = count in channel of suffix i.

When two contacts are made simultaneously, the higher number channel will count. Sometimes it is most informative to draw up a cumulative distribution plot as shown in Fig. 2.4. From this can be seen the probability that a certain value is exceeded. (Or by subtraction from unity, the probability of levels less than this value). This time, if the level lies in band 5 channels 1, 2, 3, 4 and 5 must all count. In position "Cumulative"

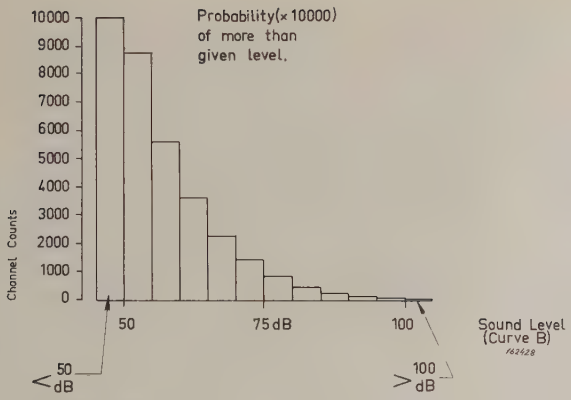


Fig. 2.4. Cumulative plot, from which can be deduced the probability that the quantity investigated is of more than a certain value.
Settings: 4420: Cumulative
Total 10,000 digits, period 1 sec.
2305: R.M.S.
50 dB range.

this is taken care of by the electronic "cascade trigger" which sets into motion all counters of suffix lower than that corresponding to the contact position.

When the Statistical Distribution Analyser is used in conjunction with a multichannel instrument such as the Noise Limit Indicator, where the distribution of discrete events is being studied, it may have to count in more than one channel simultaneously, depending on which contacts happen to be made. This mode, in which no special logic circuitry is invoked, is selected by the switch position "Distribution-2211".

2.6. External Operation.

It may not always be convenient to count pulses from the built-in pulse generator, for example when a special pulse repetition frequency is required, or when two 4420 s are to be synchronised together (see section 7.1), or when the phenomenon being investigated follows no particular time sequence.

When the "External Generator" connection is either shorted to ground or given a negative-going pulse, the total counter and also the counters for which contact is made will register one digit, provided the PERIOD SELECTOR switch is on "Ext."

Another connection, "Stop", makes possible the remote cut off of the pulse generator, whatever position the PERIOD SELECTOR is in.

The output from the pulse generator can if desired be fed to other instruments, in particular a second 4420.

2.7. Reset.

Before switching on the pulse generator, all the counters can be individually reset by pressing a button to the left of each window.

2.8. Power Supplies.

A tapped mains transformer enables the instrument to be used on 50 to 400 c/s power lines at 100 — 115 — 127 — 150 — 220 or 240 Volts.

Alternatively, the rectifier circuits can be by-passed and batteries used instead. Thanks to the fully transistorised circuitry, these are of low voltage, viz.:

— 20 v with respect to ground, about 2 m/a required,

+ 6 v with respect to ground, about 30 m/a required,

— 12 v with respect to ground, 1 amp drain when all the counters are running.

3. Technical Description

(This chapter may be omitted by many readers).

3.1. Block Diagram.

The last chapter explained the principle of operation of the Statistical Distribution Analyser. In fact the circuitry is not so simple as Fig. 2.1 would suggest, partly because of the channel cross-feed logic, which was glossed over, and partly for the following reason:

> Pulses which drive the counters must contain a certain amount of energy, in this case the pulse duration must be about 20 milliseconds. The bank of contacts shown in Fig. 2.1 may be mounted on the writing arm of a high-speed recorder and during one pulse several contacts will have time to open and close if the writing stylus is moving rapidly. Although the period counter has registered exactly one digit, many channel counters would register, providing, and this is another indeterminate factor, there is enough energy in the chopped pulses.

To overcome these difficulties, the 4420 contains not one pulse generator as shown earlier, but thirteen. Twelve of these, one in each channel ,are slaves which provide standard "counter pulses" on command from a master trigger-pulse generator acting via the contacts.

The various units indicated in Fig. 3.1. will now be explained.

3.2. Pulse Generator.

This is basically an unsymmetrical astable multivibrator. The pulse repetition period T is variable over a wide range, but the pulse width is fixed at 20 milliseconds. The maximum value of T is 10 secs so a long time constant is required, calling for a condenser which is large but which can also be charged extremely rapidly during the pulse. Since this can only be achieved by charging from a very low impedance source, an emitter follower has been incorporated in the circuit.

After passing through a current amplifier stage, the pulses drive the Period (total) Counter directly and are also available, via a phase inverter, at a low impedance output for external use*).

The generator is stopped when any of the controls (manual, automatic, or

*) The pulses are of correct polarity to trigger other 4420s, and also to reset the output relays in the Noise Limit Indicator Type 2211. The latter, which occurs after every count, is necessary in order to enable continuous monitoring.

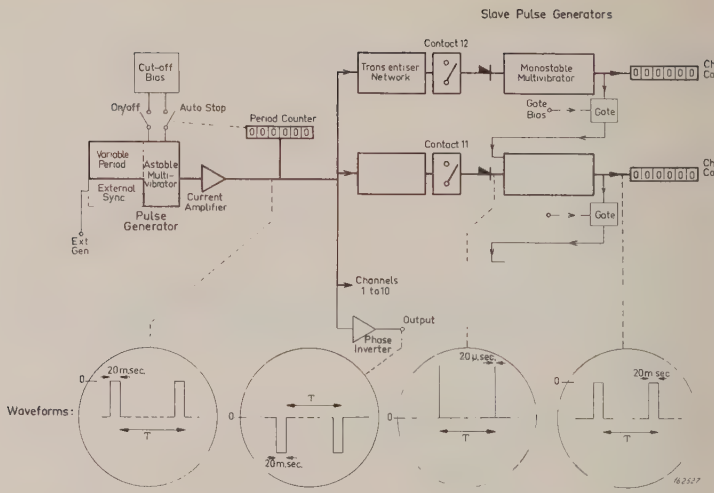


Fig. 3.1. Block diagram of the Statistical Distribution Analyser.

remote) route a cut off bias to one of the transistors. On removing this bias, the cycle begins from the start of a deadspace, see Fig. 3.2.

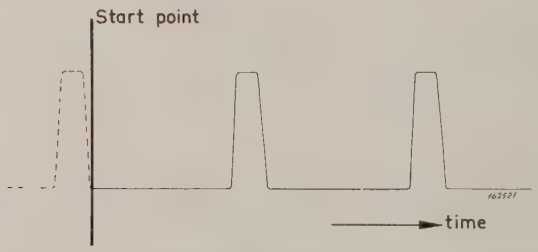


Fig. 3.2. When the pulse generator is allowed to start, the cycle commences from the beginning of a dead-space.

If the built-in timing capability is not required, the Pulse PERIOD SELECTOR switch must be turned to "External". Then, whenever the "Ext. Gen" pin of the REMOTE-CONTROL socket is shorted to ground or given a negative-going pulse**, the generator will produce one pulse only, causing one more digit to be registered on the appropriate counters.

**) The amplitude of the pulse should be between 1.2 volts and 2.5 volts and it should have a steep front,—this is the instant the generator fires,—but the remainder of the waveform is of no importance.

3.3. Transientiser Networks.

As explained in section 3.1., the pulses from the pulse generator have a duration of 20 milliseconds. The maximum velocity of the sliding contact fixed to the 2305 Level Recorder is 1000 mm/sec., so that in 20 milliseconds this contact could move 20 mm which allows five contact pairs to be made and broken. With the simple system of Fig. 2.1 this could lead to irrational registration.

To avoid this, it is arranged that the pulse available at the contacts is of extremely short duration, — 20 microseconds —, in which time the slider can move only 0.02 mm. The networks used in this part of the circuit pass one of the two spikes which result from obtaining the transient parts of a comparatively long pulse. There is one such network in each channel and before the spike can be effective in triggering, the D.C. level must be shifted by grounding a point in the network via the contacts. The common strip in the contact set is in fact grounded and not as suggested in Fig. 2.1.

3.4. Monostable Multivibrators.

The 20 microsecond spikes from the transientiser networks do not contain sufficient energy to drive the channel counters. In every channel there is therefore a monostable multivibrator which can be triggered by the spikes to produce standard 20 milliseconds pulses which can drive the counter. Since the multivibrators are monostable, the resulting numerical count represents exactly the number of spikes generated for a particular channel.

3.5. Gates.

These gates can perform either blocking or cascade triggering functions. They consist of semiconductor diodes which are biased in various ways according to the setting of the FUNCTION SELECTOR switch.

When the switch is on "Distribution — 2211" the gates can be disregarded. In position "Cumulative", trigger pulses can pass down from one channel

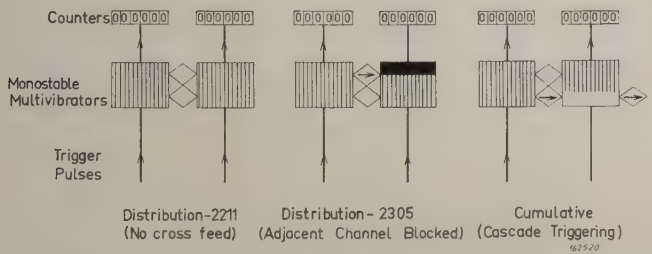


Fig. 3.3. Operation of the gates for blocking and cascade triggering. The conditions of two adjacent channels are shown for each setting of the FUNCTION SELECTOR.

to the next of lower order. For example, if contact pair number 9 is made, pulses will reach counter No. 9 and will also be passed on to trigger counter No. 8, which in turn will trigger counter No. 7 and so on. The first nine counters will register but not Nos. 10, 11, and 12.

If it is assumed that the sliding contact on the Level Recorder lies mid-way between two fixed contacts, trigger spikes will reach two adjacent channel multivibrators, say numbers 4 and 5. Counter No. 5 will receive a pulse in the usual way but, on the setting "Distribution—2305", the gate between channels 5 and 4 is so arranged that this pulse also completely blocks multivibrator No. 4, making it insensitive to any trigger spikes that may reach it.

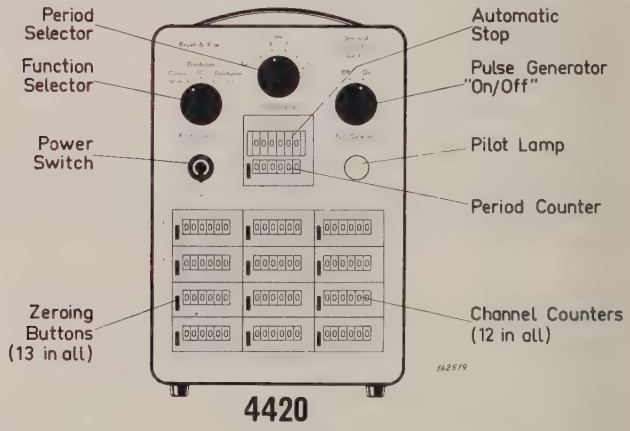


Fig. 4.1. Front view of the Statistical Distribution Analyser Type 4420.

4. Control Knobs, Sockets Etc.

4.1. Front Plate.

PERIOD SELECTOR. For choosing a suitable period between each count or for selecting external operation

FUNCTION SELECTOR. Determines the mode of counting.
"Cumulative": with Level Recorder.
"Distribution — 2211": with Noise Limit Indicator or special arrangements counting events.
"Distribution — 2305": for probability distribution histograms using Level Recorder.

POWER "on/off". Controls the supply of power from the A.C. mains, but does not influence battery power supplies if these are used instead of the mains.

AUTOMATIC STOP. The maximum desired count, or target figure, is set behind the coloured window. When the period counter reaches this figure, counting stops. The drums are rotated by the finger, having raised the window while pressing the button to the left of the Period Counter.

PERIOD COUNTER. Counts the total number of elapsed periods and can therefore be used as a total register.

PULSE GENERATOR. For switching the pulse generator on or off, i.e. for starting the counting, and for stopping it if the Automatic Stop has not already done so.

PILOT LAMP. Indicates the instrument is drawing power from either the mains or a 12 volt accumulator. When batteries are used, two dry batteries are needed in addition to the accumulator, but this lamp gives no indication that they are connected.

ZEROING BUTTONS. On being pressed in manually, each of these buttons returns the corresponding counter to zero.

CHANNEL COUNTERS. These are used to show the distribution of levels.

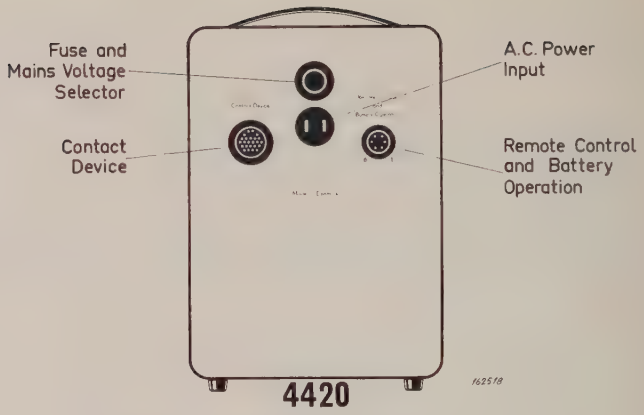


Fig. 4.2. The rear of the instrument.

4.2. At The Rear.

FUSE AND MAINS VOLTAGE SELECTOR. Cartridge fuse in series with primary of mains transformer. Selector for setting correct A.C. supply voltage.

A.C. POWER INPUT. For connecting to mains lead. (100 to 240 volts).

REMOTE CONTROL AND BATTERY OPERATION. Connections for external control of the instrument, and also for batteries should these be preferable to a mains supply. See Fig. 7.1 for further details.

CONTACT DEVICE. Amphenol 165.26 socket (B & K number JJ 2401) for connection to contacts, i.e. lead to Level Recorder via Contact Device AO 0036, or to Noise Limit Indicator. For specific connections consult Fig. 7.2.

5. Operation with Level Recorder

This chapter deals with standard procedure only. Special systems which incorporate the Level Recorder are mentioned in chapter 7.

5.1. Supply Voltage.

The apparatus may be operated from mains supplies of any frequency between 50 and 400 c/s but the voltage selector, to be found at the back, must be correctly set to the supply voltage. If it is not, unscrew and withdraw the cartridge fuse and then, with the aid of a coin, turn the selector until the white bar is in the desired position. Replace the fuse.

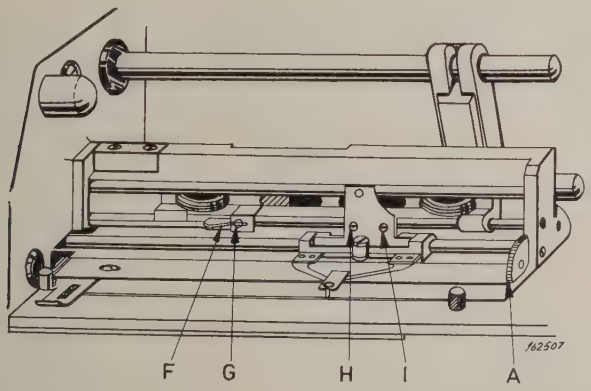


Fig. 5.1. Identification of the relevant parts in the 2305 writing system.

5.2. Attaching Contact Set.

I. With the recorder's POTENTIOMETER RANGE dB on "Stand-by", remove the cover from the writing arm unit on the Level Recorder Type 2305.

II. Lift the mechanical lifting cam A (Fig. 5.1).

III. Ensure that the writing mechanism is set for a chart width of 50 mm, if it is not, see Fig. 5.1 and:

a. Remove the driving arm with its wishbone-type head F from drive lug G, by pressing the inner leaf of F gently inwards (for example

by means of a pair of tweezers), extending the wishbone outer leaf, so that the inner leaf can be disengaged by moving the bogie to the right.

b. Holding the driving arm in a forward position and at the same time resting it on the face of the lug G, push the bogie towards F. Guide the wishbone head so that it engages the two-holed lug on top of the bogie and insert the stop on wishbone inner leaf in first hole H.

IV. Replace the standard cover by the Contact Device AO 0036, making certain that it is located over the rounded screw-head at the right-hand end, and properly bedding down on the flanges at the left-hand end.

V. Take the Contact Slider OD 0130 and slacken off the securing screw (see Fig. 5.2) so that the expanding collet asumes its minimum diameter. Do not remove the screw completely since it retains a ball which may be lost.

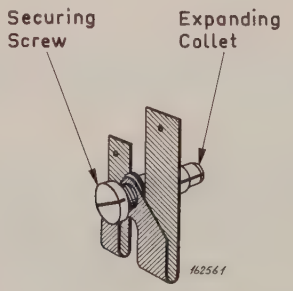


Fig. 5.2. Contact Slider OD 0130.

VI. Push the expanding collet right home into the unoccupied hole I in the two-holed lug on top of the writing bogie. (Refer to Fig. 5.1). Make certain that the Contact Slider is bedding down nicely on the fixed contact. Tighten the securing screw just enough for it to depress the enclosed ball so that this will expand the collet and lock the Contact Slider in position.

VII. Clean all contact faces with a soft rag and methylated spirits; on no account use abrasives since the surfaces are plated with gold and rhodium.

VIII. Check that the Contact Set is connected to the 4420 via the CONTACT DEVICE socket.

IX. Switch on the 4420 and with PULSE GENERATOR control "On", the PERIOD SELECTOR set for any fast count, and the FUNCTION

SELECTOR in any position, check that all the counters can register as the Level Recorder bogie is moved from side to side with the fingers. If the 4420 will not count at all, it may be that the automatic stop is in charge so see section 5.5. which deals with the automatic stop, and prevent further interference.

If any of the channels are erratic in operation, either part VI or part VII above has not been carried out correctly and must be repeated.

X. Owing to the finite area of the moving contact face, the scale lengths over which channels 1 and 12 are operative may not be equal. For accurate measurements this can be corrected by rotating the sliding contact through a few degrees.

5.3. Setting the Level Recorder.

A graphical record of the phenomenon to be investigated is not normally

Table I. Guide to Setting Up the Level Recorder Type 2305.

Controls	A.C. Recording—that is, when the levels of some high frequency phenomenon are to be investigated, or when A.C. carrier techniques are used.	D.C. Recording—that is, when the instantaneous values of slowly varying quantities are to be investigated.
SUPPLY VOLTAGE	Check disc setting	
MOTOR	"Off"	
POTENTIOMETER RANGE	"Standby"	
RANGE POTENTIOMETER	Insert correct one, 10 dB, 25 dB, 50 dB, 75 dB, 10/35 Lin., 10/110 Lin.	
POTENTIOMETER RANGE	Set to correspond with above, viz.: "10", "25", "50", "80", "12", "16", respectively.	
LOWER LIMITING FREQUENCY	"20 c/s"	"50 c/s"
WRITING SPEED	"100/200"	"400/800"
RECTIFIER RESPONSE	"RMS", "Peak", or "Average" as required.	"D.C."
POWER	"On"	
Other Controls	May be in any position	
INPUT ATTENUATOR INPUT POTENTIOMETER	Adjust these so that an approximately mean level corresponds to the centre of contact pair number 6. (Channels are numbered from right to left.)	

necessary, but if desired a time-plot can be run of simultaneously with the statistical analysis. Use one of the recording papers QP 0102, QP 0202, or QP 0302: there is no object in using frequency calibrated paper.

Connect up the ancilliary equipment feeding the recorder. This may be a tape recorder (see section 8.1.) or, for example, a B & K Spectrometer Type 2112.

With the probable exception of the paper drive which need not be used, set the recorder controls exactly as for a graphical recording, following the procedure set out on p. 23*). Some of the points which may have to be taken into consideration when investigating rapidly varying phenomena are discussed in Appendix B.

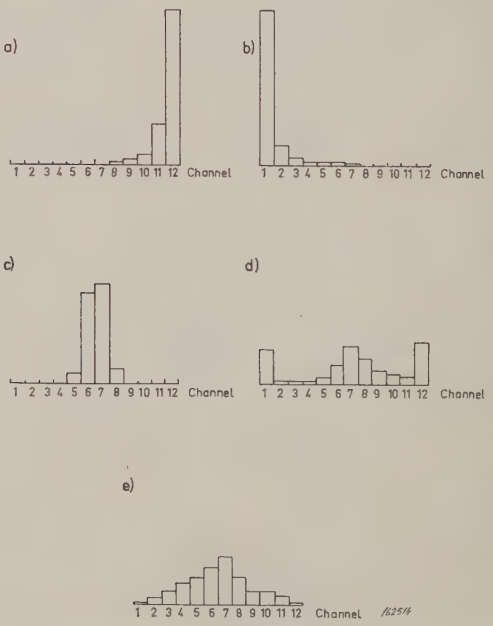


Fig. 5.3. Histograms illustrating the importance of choosing satisfactory dynamic level and range on the Level Recorder.

a) and b) Mean level badly chosen
c) RANGE POTENTIOMETER for too wide a range
d) RANGE POTENTIOMETER for too narrow a range
e) Usually the best kind of diagram to aim for.

*) For further details, see the 2305 Instructions and Applications Manual.

Check that a satisfactory recording range is obtained, i.e. that proper use ise made of all the available contacts. If insufficient attention is paid to this point, the results may be misleading and not very instructive, as illustrated in Fig. 5.3.

Note the RANGE POTENTIOMETER used and the calibration of the system. The recorder must be "writing" before starting the Statistical Distribution Analyser.

5.4. Zeroing the Counters.

Switch the 4420's PULSE GENERATOR to "Off".

Momentarily press in each of the 13 black buttons to the left of the Counters.

5.5. Setting Target Figure.

Push in the black button which zeroes the total counter and while it is depressed, roll the transparent orange shutter in an upward direction, exposing the target counter.

Release the zeroing button and rotate each drum independently with the fingers until the desired target figure appears. It is convenient to set some power of 10, and if the automatic stop is not needed, set a high figure which will not be reached.

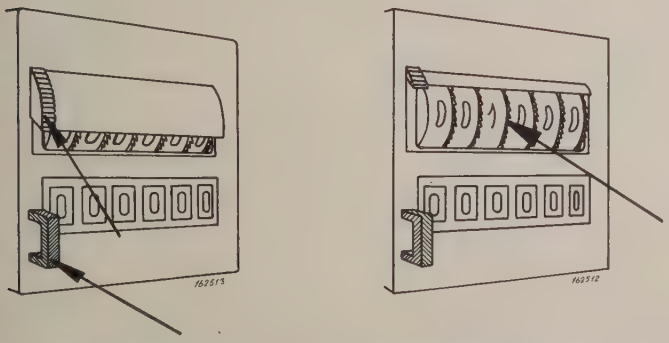


Fig. 5.4. To set the target figure, a) lift the transparent coloured window, and b) rotate the counter drums with the finger.

5.6. Counting Rate.

Move the PERIOD SELECTOR to the required pulse repetition period. Generally speaking it is better to use a fast counting rate and a high target figure: this matter is considered theoretically in Appendix B.

5.7. Counting.

Decide whether a histogram giving probability distribution is required, or whether a cumulative probability plot would be more useful*). Switch the FUNCTION SELECTOR to "Distribution—2305" or to "Cumulative" as required. Switch PULSE GENERATOR to "On".

It is usually best to rely on the automatic stop, though counting can be halted by switching the PULSE GENERATOR to "Off", and the instrument may be left unattended for any length of time before returning to note down all the numbers.

5.8. Tabulation.

In the case of "Distribution—2305" it is worth checking that the sum of the channel counts equals the total count. If it does not, the contact set probably requires cleaning.

If the mean and variance or degree of skewness etc. are to be calculated, it is easiest to do this first in terms of "channel units", of which there are exactly 12. The results can then be converted to the required units by referring to the recorder calibration and range.

Appendix A gives some guidance on working out the basic data.

*) These are explained in Chapters 1 and 2.

6. Operation with Noise Limit Indicator

6.1. Preliminaries.
Carry out the operations specified in sections 5.1, 5.4, 5.5, and 5.6.

6.2. Coupling to the Noise Limit Indicator.
The Indicator Box supplied as standard equipment with the Noise Limit Indicator Type 2211 cannot be used: the Statistical Distribution Analyser

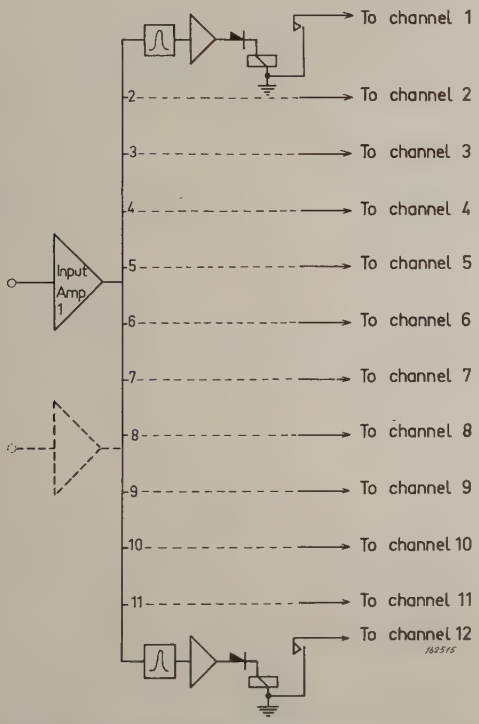


Fig. 6.1. Connecting the 4420 automatically selects Input Amplifier I in the 2211.

is connected in its place. Using the 24-core cable delivered with the 2211 equipment, couple the 4420 to the socket marked CONTROL PANEL at the back of the Noise Limit Indicator's main unit. The Contact Device AO 0036 is of course redundant and must be unplugged so that the 24-core cable can be connected to the CONTACT DEVICE socket.

6.3. Condition of the Noise Limit Indicator.

When the two units are coupled together there are no control buttons for the Noise Limit Indicator. The 2211 is automatically put into the following condition:

I. Input Amplifier I is always connected. It is not possible to use Input Amplifier II.

II. There is no "sensitivity increase" facility. This is not required for applications involving statistical analysis of varying levels.

III. Since monitoring is continuous, there is no "release" button.

IV. The output relays are automatically reset after each count by a pulse from the 4420. This is to allow continuous monitoring of levels, otherwise a channel would count incessantly after its relay had once been closed.

6.4. Setting the Noise Limit Indicator.

Connect an accelerometer or microphone to Input Amplifier I, and carry out the setting-up procedure for this amplifier and for all the output amplifiers (adjust black knobs). See 2211 manual.

6.5. Counting.

Set the FUNCTION SELECTOR to "Distribution-2211", the PERIOD SELECTOR to any suitable rate, and finally (after putting the whole measuring system into operation), switch the PULSE GENERATOR "On".

7. Operation With Other Equipment

This chapter contains a few suggestions for use of the 4420 in conjunction with equipment not supplied by Brüel & Kjær.

7.1. Coupling Together.

There are cases where more than 12 class intervals would be desirable for a statistical analysis. A Level Recorder (preferably set for 100 mm writing range) could then be fitted with 24 or 36 special contacts. The contacts could be divided into groups of 12, each of which would be led off to separate 4420's for registration. Obviously it would be advantageous to synchronize the counting of all the analysers.

Choose one 4420 as master. Switch its PERIOD SELECTOR to whatever counting rate is required. Trigger pulses are now available at pin 7 of its REMOTE CONTROL AND BATTERY OPERATION socket (Fig. 7.1).

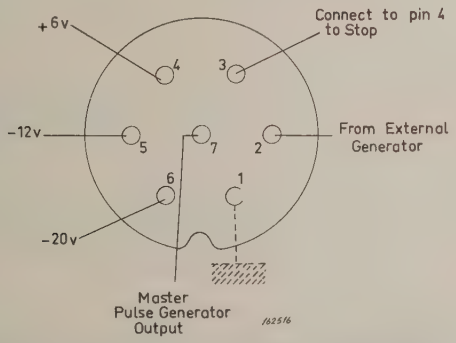


Fig. 7.1. REMOTE CONTROL AND BATTERY OPERATION socket, viewed externally. The D.C. voltages shown are those to be applied from three batteries, which may be used as an alternative to the A.C. mains.

Switch the PERIOD SELECTOR on all other 4420's to "Ext.". These slave units will not now count unless a trigger pulse arrives at pin 2 on their REMOTE CONTROL sockets. Therefore, connect all grounds (pins 1) together, and feed pin 7 on the master to pin(s) 2 on the slave(s).

The procedure as regards other features of operation is not affected, except that in cases where the number of contacts is an exact multiple of 12 (as

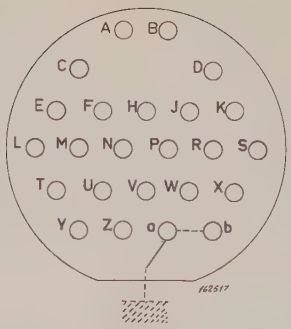


Fig. 7.2. CONTACT DEVICE socket, viewed externally. Pin A is the live contact for channel 1, pin B for channel 2, and so on up to pin N which is for channel 12. Pins a and b are earthed, i.e. common to all contact pairs

above) "Cumulative" and Distribution—2305" readings must be used with discretion, because the electronic cascade triggers and blocking networks cannot transfer their influence from one 4420 to another.

If these facilities are necessary, it is best to use 23 or 34, etc. channels as shown in Fig. 7.3. Counter 12 of unit I then reads the same figure as counter 1 of unit II, but now the complete system is operating correctly.

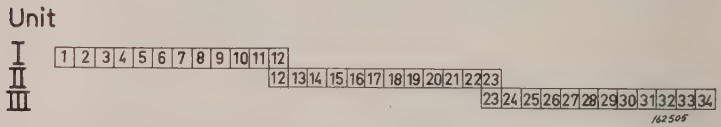


Fig. 7.3. Coupling together. Pin N (Fig. 7.2.) of unit I is connected to contact 12, but so also is pin A of unit II. Similarly, pin N of unit II would be connected to pin A of unit III. The count in channel 12 (and 23) appears twice, but the electronic blocking networks and cascade triggers are operative between all 34 channels.

7.2. External Triggering.

Instead of taking trigger pulses from another 4420, the master can equally well be a make contact or negative-going pulse applied between pins 1 and 2. (Fig. 7.1.). The nature of the external pulse is discussed in section 3.2.

This facility is valuable when the analyser is to be synchronized with some process which does not obey any strict time-sequence.

7.3. Battery Operation.

Fig. 7.1. shows where batteries are connected when these are more convenient than the A.C. mains. The 12 volt supply should be from an accumulator such as a vehicle battery, but the 6 and 20 volt sources need

only be from low capacity dry cells. To switch off, it is necessary to disconnect the batteries. The POWER "On/Off" switch does not influence battery supplies and the pilot lamp monitors only the 12 volt circuits.

7.4. Remote Stop.

The apparatus can be stopped regardless of the counting condition prevailing, if pins 3 and 4 (Fig. 7.1) are shorted together. This is effective both for mains operation and when batteries are in use.

7.5. Non-standard Contacts.

If the channel counters are to operate via special relays or contacts, make the necessary connections according to Fig. 7.2. Remember that these contacts only govern *which* channel is capable of counting. *When* a count will occur is governed by the PERIOD SELECTOR and, where applicable, external circuitry.

8. Some Applications

8.1. General.

Many applications of the Statistical Distribution Analyser involve sound measurement and, of course, the Level Recorder Type 2305. It is often very convenient to record the signal of interest on magnetic tape using, for instance, the arrangement shown in Fig. 8.1. The signal should be recorded

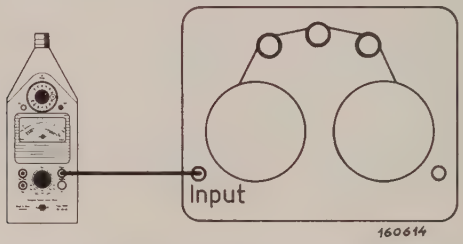


Fig. 8.1. Tape recording is a convenient basis for analyses. In this illustration a B & K Sound Level Meter is being used with a battery operated tape recorder.

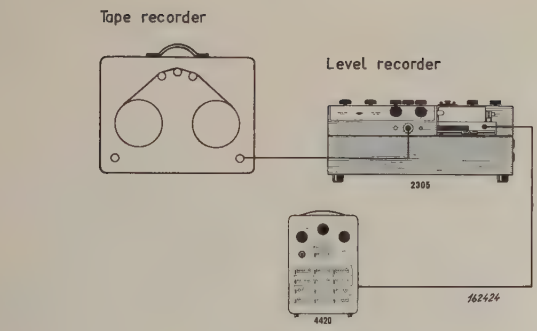
wideband, so that on playing it back, different filters and weighting networks can be inserted between the tape recorder and the Level Recorder. (Fig. 8.2). If an extremely accurate calibration signal is required this can be obtained from a Pistonphone Type 4220.

8.2. Noise Control.

The random nature of so many of the annoying sounds which need to be brought under control has made the collection and correlation of data very difficult. The 4420 can be used to simplify this task considerably; some of the specific problems are

Airport Noise,
Traffic Noise,
Office Noise (Fig. 8.3)
or Assembly Hall Noise (Fig. 8.4).

As an example of the usefulness of such statistical information one might take the case of the acoustic expert designing insulation in walls. He wants to know a) "What is the mean level I have to consider?", and b) "How likely



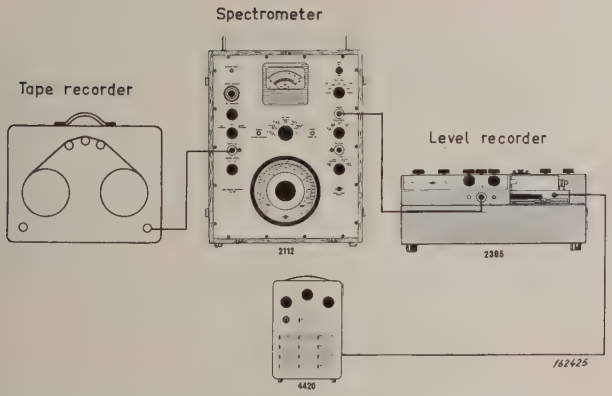


Fig. 8.2. Analysing recorded sound.
a) Wideband.
b) Via suitable filters.

is it that the background noise will be too low", — this is often a major factor governing privacy —, or "how likely is it that the sounds will be so loud that my insulation is inadequate?".

8.3. Physiological Damage Studies.

It may be that a great deal of important data can be deduced from specialized calculations on statistical information from the 4420; i.e. product functions of sound intensity multiplied by exposure times etc.

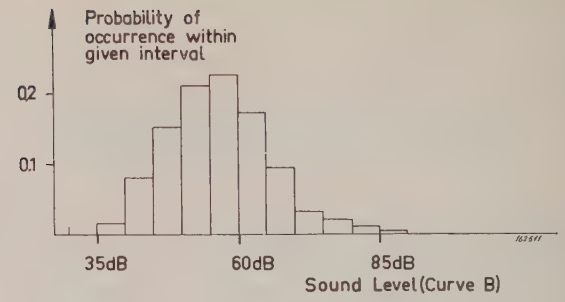


Fig. 8.3. Probability distribution histogram of sound level (B) in an office, taken over 10,000 × 1.0 sec.

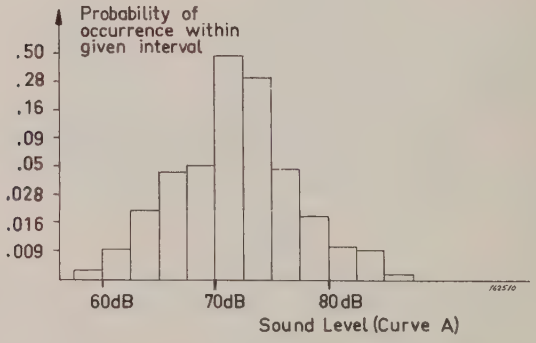


Fig. 8.4. Probability distribution histogram of sound level in an exhibition hall. Note the logarithmic ordinate used here because the probability of high and low values was very small.

8.4. Mechanical Design.

For optimal design of structures subjected to random loading it is important to make a reliable estimate of the larger stresses involved and the probabilities of these occurring. In the case of acoustic and vibration fatigue investigations the Level Recorder can record levels for statistical analysis, and in the case of low frequency strain measurements it can be switched to record the D.C. strain signals from a Strain Gauge Apparatus Type 1516. A linear range potentiometer is normally used for strain measurements, — see Figs. 8.5 and 8.6.

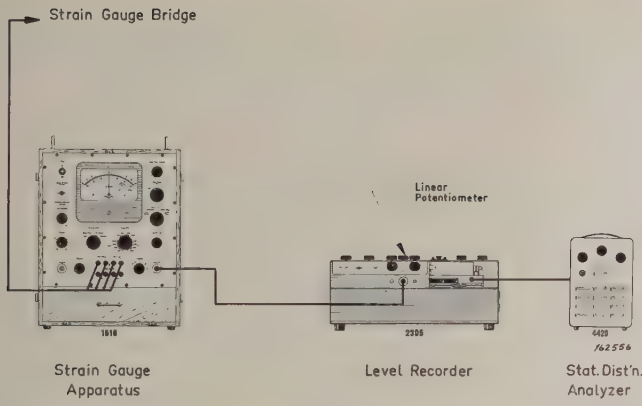


Fig. 8.5. Strain Gauge Apparatus Type 1516 coupled to a Level Recorder and Statistical Distribution Analyser.

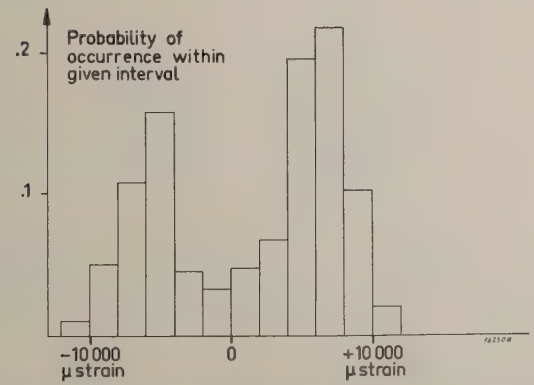


Fig. 8.6. Statistical analysis of strain in structures provides valuable information concerning behaviour under operating conditions. This histogram shows the distribution (taken over one day) of strains in a radio mast. It is interesting that in this case, where the weather was stormy, zero strain did not occur often, whereas a similar experiment in calm weather resulted in a more conventional shape of distribution, centred on zero.

8.5. Performance Assessment.

A Level Recorder can be incorporated in an arrangement capable of measuring many quantities but it is not always the most convenient or practical recorder to use. Special contact sets could, however, be made so that data for the 4420 could be taken from the recorders used in practice for measuring.

Signal strength of broadcasting, TV, or communications links,
Drawbar pull of locomotives etc.,
Pressures in compressors etc.,
Temperatures.

On development tests and type-approval trials of machinery a great deal can be learnt from splitting one microphone or accelerometer signal into various frequency components. Then, whenever some selected signal exceeds a pre-determined level, the fact could be registered by a 4420 connected to a Noise Limit Indicator Type 2211. This particular kind of test is illustrated in Fig. 8.7.

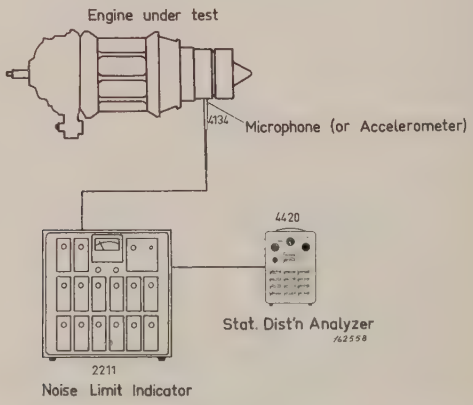


Fig. 8.7. Sound or vibration time-histories in twelve different frequency bands can be monitored over a long duration by using a Noise Limit Indicator Type 2211.

8.6. Classification.

With the aid of special accessories, the 4420 can be used for classifying some property in twelve categories. Fig. 8.8 is intended to show the general principle rather than being a sketch of a practical set-up. The important point is that before a count occurs the article is grouped under a certain category ("11" say), and then while this contact is still made, a switch

commands the 4420 to count one digit in the total register and in channel 11. This is not a strictly time- dependent operation so the 4420 must rely on an "external" command to count.

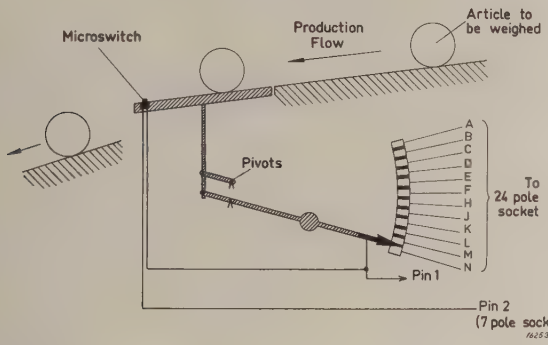


Fig. 8.8. Automatic weight register, showing the principle of a typical "classification" system. The 4420 is switched to "External" operation and will not count until Pin 2 is grounded. Each time this happens it will count only one more digit. Note that the correct contact A to N must be chosen before a count occurs and then the system must be given time to readjust itself to classifying the next article before another count is allowed.

Appendix A

Useful Formulae.

Suppose that, using the "Distribution — 2305" setting, a histogram has been drawn up — Fig. A.1. The total count is N, and that in channels 1,2, 3, ... 12 is n_1, n_2, n_3 ..... n_{12}.

$$\text{i.e. } N = n_1 + n_2 + n_3 + \ldots\ldots n_{12}.$$

It must now be assumed that there has been no appreciable overshoot of the recorder writing arm, either above or below the scanned range. In other words, n_1 and n_{12} must represent a finite interval which is the same as that for other channels: they must not be lumped totals for much wider intervals.

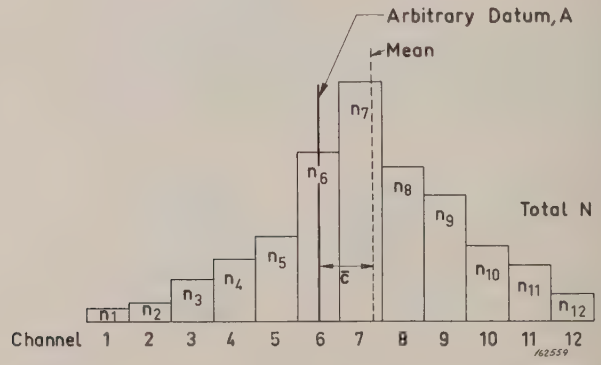


Fig. A.1. Nomenclature for the formulae. ("Distribution — 2305" setting).

Calculating Mean:

It is best to work in "channel units", of which there are exactly 12, and then to convert to realistic units at the final stage. This is simple because the chart width (representing a known range) is divided into ten channel units.

If the mean is likely to be somewhere near the centre of the recorder scale, it is convenient to choose the mid-point of interval 6 as an arbitrary datum, A. (See Fig. A.1). The mean lies above A by an amount $\bar{c}$ channel

units. The mean gives, in effect, the axis of the centre of gravity of a flat plate cut out to exactly the same shape as the histogram.

$$\bar{c} = \frac{1}{N}\left[(n_7 - n_5) + 2(n_8 - n_4) + 3(n_9 - n_3) + 4(n_{10} - n_2) + 5(n_{11} - n_1) + 6n_{12}\right] \quad \ldots . 1$$

In terms of realistic units, A and the scaling in channel units are known from the recorder arrangement, so a best estimate of the actual mean is easily found from $A + \bar{c}$ channel units.

Calculating Standard Deviation:

The square of the standard deviation (i.e. the variance) is analogous to the radius of gyration of the above mentioned plate about its centre of gravity. To simplify calculation, the following formula takes A as a datum once again, and assumes (as is justified) that N is a large number.

Best estimate of variance,

$$\sigma^2 = \frac{1}{N}\left[(n_7 + n_5) + 4(n_8 + n_4) + 9(n_9 + n_3) + 16(n_{10} + n_2) + 25(n_{11} + n_1) + 36n_{12}\right] - \bar{c}^2 \quad \ldots . 2$$

Hence the standard deviation, in channel units, subsequently converted to realistic units.

Example:

Consider the case quoted in Fig. 8.3 (office noise) Channel Readings:

	1	5
	2	173
	3	798
	4	1521
	5	2109
	6	2231
60 dB →		
	7	1682
	8	928
	9	297
	10	190
	11	57
	12	9

Range Potentiometer: 50 dB.

1 Channel unit = 5 dB.

A = 60 dB — half a channel unit = 57.5 dB.

N = 10000	n_7 1682 n_5 2109	n_8 928 n_4 1521	n_9 297 n_3 798	n_{10} 190 n_2 173	n_{11} 57 n_1 5	n_{12} 9
Difference	— 427	— 593	— 501	17	52	9
Sum	3791	2449	1095	363	62	9

Equation 1 gives

$$\bar{c} = \frac{-427 - 2\,(593) - 3\,(501) + 4\,(17) + 5\,(52) + 6\,(9)}{10{,}000}$$

$$= -0.2734 \text{ channel units} = -1.36 \text{ dB}$$

$$\text{Mean} = 57.5 - 1.36 = 56.14 \text{ dB}$$

$$\text{say } 56 \text{ dB}$$

Equation 2 gives:

$$\sigma^2 = \frac{3791 + 4\,(2449) + 9\,(1095) + 16\,(363) + 25\,(62) + 36\,(9)}{10{,}000} - 0.075$$

$= 3.112 - 0.075 = 3.137$ (channel units)^2

Standard Deviation = 1.77 channel units = 8.85 dB ~ 9 dB.

Appendix B

Analysing Rapid Fluctuations.

When the Statistical Distribution Analyser Type 4420 is coupled to the Level Recorder Type 2305, the capabilities for analysing rapidly fluctuating signals will depend upon:

the counting rate of the 4420, and
the response of the 2305.

The two instruments may be considered separately; obviously the weaker link in the chain will determine the limitations of the whole system.

Counting Rate:

The maximum counting rate is 10 per second. This is valid both for the built-in generator and for external triggering.

The pulse repetition period is therefore one-tenth of a second. What happens if a wave of exactly the same — or shorter — period is analysed? Fig. B.1 shows how so-called "aliasing" errors can arise in these cases.

As a working rule, a fairly smooth waveform should be sampled five times in any half-period in order to get a useful impression of its statistical

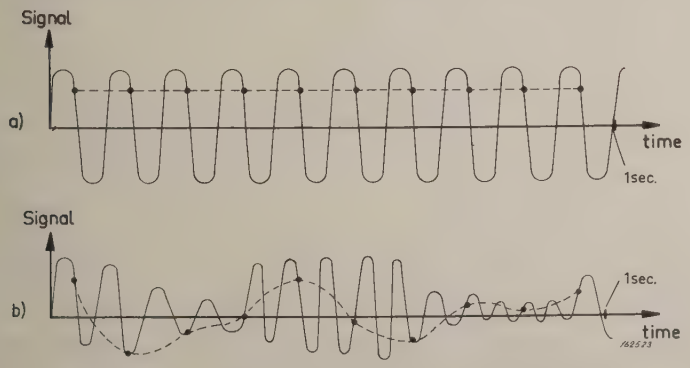


Fig. B.1. Comparatively slow sampling of a fast wave.
a) If the wave frequency is the same as, or a multiple of, the counting rate, no periodicity can be distinguished at all.
b) Samples such as these could give the correct mean value but incorrect variance.

properties. An irregular waveform, where peculiar fluctuation are of interest, needs to be sampled at least 10 times in any half-period*). Thus the 0.1 sec sampling period dictates a maximum level-fluctuation frequency of 1 c/s (or 0.5 c/s for irregular shapes).

Recorder Response:

Fig. B.2 shows the response of the 2305 to low-frequency amplitude variations. In fact the above requirement for faithful recording up to 1 c/s does not make any very high demands; it only requires that the writing speed must be 250 mm/sec or faster. It is explained in the 2305 manual that, with this writing speed, the Lower Limiting Frequency (L.L.F.) must be 20 c/s or greater in the interests of recorder stability. 20 c/s L.L.F. should allow

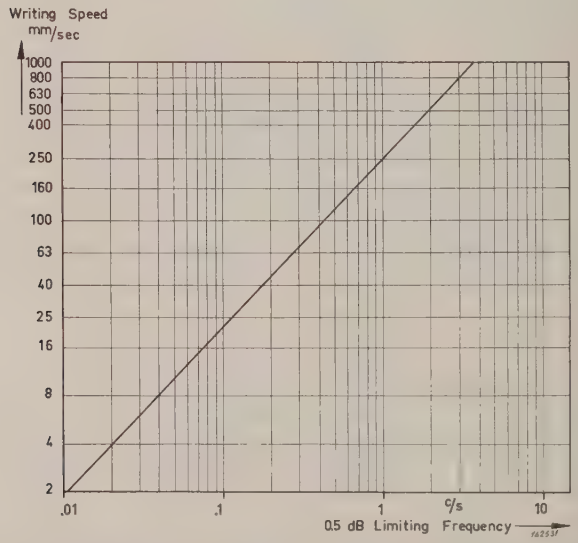


Fig. B.2. The maximum frequency at which the Level Recorder will respond faithfully to slowly varying signal levels is determined by the writing speed and writing amplitude. For maximum excursions of the writing arm, the useful upper frequency limit is plotted here against writing speed. When the excursions are smaller, the upper frequency limit becomes greater; in other words, the line on the graph moves towards the lower right corner. (With very small fluctuations it passes, almost parallel with the given line, through the point 1 c/s, 40 mm/sec.).

*) For a full discussion on allowable sampling frequencies, see for instance J. S. Bendat, "Principles and Applications of Random Noise Theory". (Wiley).

perfect signal rectification for most purposes. There is no object in increasing the writing speed beyond 250 mm/sec because the 4420 cannot then follow all the variations correctly.

For many acoustic measurements, the analysis should bear some relation to changes in level as discerned by the human ear. This means that the recorder averaging time should approximate the averaging time of the hearing mechanism. The latter is thought to lie between some 50 to 200 msec, and this corresponds to a writing speed of between 160 mm/sec and 40 mm/sec. Even the fastest of these speeds (smallest averaging time) allows variations which can be followed by the 4420, but it is a useful rule to specify 100 mm/sec for these acoustical investigations, the counting rate on the 4420 being 10 per second. Of course, when the noise levels build up and decay comparatively slowly — airport noise for example — the time constant of the human ear is not a critical factor and slower counting rates are allowable.

Specification

For Attachment to: Level Recorder, Type 2305, via sliding contacts
Noise Limit Indicator, Type 2211.
Other indicators where there is a suitable system.

Discrimination: 12 bands covering given data range.

Display: 13 window counters, drum type: comprising one total register plus 12 channel-counters. Figure height 4 mm.

Maximum Count: 999,999 for all counters.

Counting Rate: Built in generator giving one count every
0.1
0.3
1
3
or 10 secs as required.*)
External contacts or pulses can trigger generator one shot at a time for any rate slower than 10 per second.

Presentation: Distribution of discrete events, possibly simultaneous. All channels operative.
Cumulative count of levels exceeded by one variable.
Distribution of one continuous variable, i.e. total count = sum of channel counts.

Automatic Stop: At any pre-determined figure up to 999,999.

Remote Control: Of triggering one-shot generator and of stop. Two or more 4420 s can be connected together to obtain more channels.

Reset: Manual; individual counters.

Semiconductor Devices: 26 × ACY20, 34 × OA79, 14 × OA85, 1 × 2N388, 1 × SFT253, 1 × 2S302.

*) When the instrument is battery operated the pulse generator does not always work in the 10 sec/period position.

Power Supply:

Either A.C. Mains;
100—115—127—150—220—240 volts A.C., 50 to 400 c/s.
Consumption about 15 watts.
Or alternatively, three batteries;
20 volts, delivering about 2 mA
6 volts, delivering about 30 mA
12 volts, delivering 1 amp. max.

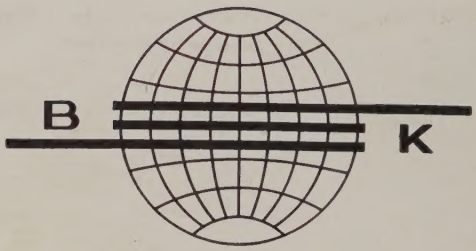
Dimensions:

excluding knobs and buttons etc.

Height	10″ (26 cm)
Width	7″ (18 cm)
Depth	5″ (13 cm)

Accessories Supplied:

Contact Set for attachment to Level Recorder, power cable, spare panel lamp and fuses.



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